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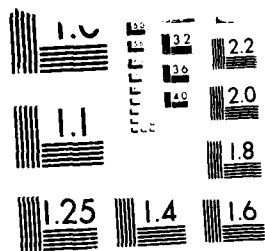
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THE FLIGHT DEVELOPMENT OF A COLOUR ELECTRONIC
DISPLAY FORMAT AND MONITORING SYSTEM
OF HELICOPTER ENGINE AND TRANSMISSION DATA

by

R. Little
Lt Cdr R. Cowan RN

June 1986

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SUMMARY

A Wessex helicopter at RAE Bedford has been used to develop and evaluate an integrated avionics system which incorporated electronic displays and a flight management system for both military and civil applications. A key feature of this system was the display of engine and transmission data. This was complemented by a system monitor which provided visual and audio warnings of limit exceedences, parameter mismatches, and failures.

The flight trials showed that the display of engine and transmission data could be advantageously suppressed and only shown when the pilot requested it or a monitor detected a problem. When used in combination with synthetic voice the monitoring system allowed the pilot to concentrate upon tasks more relevant to the current phase of flight. Safety and mission effectiveness were therefore enhanced.

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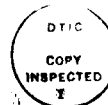
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LIST OF CONTENTS

	<u>Page</u>
1 INTRODUCTION	3
2 THE DISPLAY AND MONITORING OF CRITICAL DATA	3
3 THE 'TEES AND PEES' FORMAT	4
4 THE HEALTH MONITOR	6
4.1 Failures and warnings	6
4.2 Power performance index (PPI) and health monitoring	7
4.3 Aircraft performance	7
4.4 Icing	7
5 FLIGHT RESULTS	8
5.1 Engine starts	8
5.2 Flight monitoring	8
5.3 Warnings	8
5.4 Checks	9
5.5 Layout of the TEES and PEES format	10
5.6 Primary flight display	10
6 CONCLUSIONS	11
Appendix A The Wessex facility	13
Appendix B Trials programme and procedures	16
Table 1 Audio warnings	18
Table 2 Health monitor checks	19
References	20
Illustrations	Figures 1-13
Report documentation page	inside back cover

1 INTRODUCTION

A Wessex 2 helicopter at RAE Bedford has been used to evaluate a suite of experimental avionics in flight. A set of microprocessors was used to integrate the cockpit controls and displays to a variety of flight, mission and utility systems. The cockpit systems comprised a set of colour CRT displays, automatic speech recognition (ASR), synthetic speech output (SSO), a monochrome chin-up control and display unit (CDU), and touch overlays for displays. The experimental cockpit systems were arranged on the left hand side of the instrument panel as shown in Fig 1. The remaining electro-mechanical instrumentation was used by the safety pilot on the right hand side. The total cockpit was night vision goggle (NVG) compatible. The equipment and software were integrated to provide a user friendly advanced cockpit avionics and flight management system which could form the core of any future helicopter cockpit package.

This Memorandum, which is one in a series concerned with different sub-systems in the Wessex, describes the development and use of a colour display format of engine, transmission, and hydraulic data which was complemented by a system monitor of limit exceedences, mismatch conditions and failures. Warnings could be given both visually and aurally. A detailed description of the Wessex facility is given in Appendix A and Ref 1.

The purpose of the development programme was two-fold:

- (a) To determine how the total pilot cockpit display interfaces and supporting avionics could best be integrated and flight management data presented to a pilot to optimise his performance, reduce workload, and hence increase the overall mission effectiveness.
- (b) To demonstrate a representative FLYING system to Service and Civil operators, and UK Industry and to stimulate their appreciation of the benefits that new technology offers when used to advantage.

2 THE DISPLAY AND MONITORING OF CRITICAL DATA

During all modes of flight one of the colour displays was used to present primary flight data. This primary flight format, shown in Fig 2, contained sufficient relevant data to enable the pilot to control, navigate and land the helicopter without reference to any other display. In addition it contained a rotor RPM presentation which was considered to be of primary importance.

The second colour display was used as a Multi-Function Display (MFD) to present data pertinent to the task in hand. During most phases of flight this would be the navigation format, comprising a digital map with route overlay, waypoints and tactical data, as shown in Fig 3. The pilot could select several other formats, one of which was the engine, transmission and hydraulic monitor format (colloquially termed the TEES and PEES format). This was used during engine starts and during flight whenever the pilot wished to check the data presented on it. However, during most of the flight the TEES and PEES information was suppressed and the MFD was used for other tasks. The monitoring system checked the engine and transmission data continuously and any errors were

flagged to the pilot. This could be done by a combination of synthetic speech warning⁴ and the use of changes in colour to present out of limits parameters on the PFD. Alternatively, it could involve a complete MFD format change, CDU display change and voice warning.

3 THE 'TEES AND PEES' FORMAT

From the outset of the research programme it was decided that a single format of engine and transmission parameters, if it was possible to develop, would be preferable to a number of formats showing similar data for different modes of flight. This would simplify the pilots task as a single format could be called to assess the total engine and transmission 'health' at any time. It would thus allow the pilot to start engines as well as monitor their health and diagnose failures in flight.

Obviously, such a format could be very cluttered and great care was taken to ensure that a clear, friendly format was developed. The information which needed to be displayed was:

- (a) rotor rev/min (Nr)
 - port and starboard compressor rev/min (Ng)
 - port and starboard free power turbine speeds (Nf)
 - port and starboard power turbine inlet temperature (T4)
 - port and starboard fuel flows
 - port and starboard fuel tank contents
 - rotor torque
- (b) primary and secondary hydraulic pressure
 - port and starboard engine oil temperature
 - port and starboard engine oil pressure
 - coupling gearbox oil pressure and temperature

The data corresponding to group (b) was unfortunately not available to the microprocessor systems during this phase of development. Nominal operational values, corresponding to cruise flight were therefore simulated during the later development phases so that a complete display format could be assessed. All of the information in group (a) was gathered in real time for display and monitoring by the management processors.

Fig 4 shows one of the initial formats that was developed and assessed. There are several features worthy of note.

Strip scales were used extensively in the display format. Although these were very efficient in terms of information density on the display, great care was taken to avoid excessive clutter and hence pilot confusion.

To complement some of the strip scales digital readouts were provided.

The rotor rev/min strip was used to separate the data relating to each engine into two areas on the display.

Non-linear scaling was adopted to amplify strip scale movement in critical areas of operation.

Parameters were grouped according to system rather than function, ie all the port engine parameters were grouped together rather than for example, the port and starboard T4 data being grouped together.

Parameters were colour coded to facilitate easier fault diagnosis and information retrieval:

A white, strip or digital readout indicated that the parameter was within its normal operating limits.

A magenta, strip or digital readout indicated that the parameter was outside normal operating limits.

The Nr strip was coloured green if it was within its normal operating limits.

Although a torque readout was displayed continuously on the PFD, a further torque display on the TEES and PEES format was thought to be necessary.

A circular 'pacman' torque display was devised to avoid yet another strip display. This took the form of a green circular 'pie'. A full pie represented 3000 ft lb. As the torque exceeded 2400 ft lb the pie was coloured magenta.

Fuel contents were displayed in digital form for each tank. The digits were magenta if the fuel reserves were low or mismatched by greater than 100 lb. A box was drawn around each set of digits to avoid confusion.

The digital readouts of Ng were updated in increments of 50 units. The T4 and fuel contents readouts were incremented in steps of 10 units.

This display format was carefully assessed by the three key trials pilots. The format was shown to be useable in all modes of flight including engine starts (see Appendix B). However, there were many criticisms and deficiencies:

- (a) There was no indication of the available operating margin to the pilot. Although the pilot could see that all the parameters were within their operating limits, because they were coloured white, he had to check each individual parameter carefully to determine how close to a limit or failure condition it was.
- (b) The fuel flow indicators were not well positioned. An important requirement in the Wessex was that the fuel flows should be matched by the pilot. These parameters should therefore be grouped closer together.
- (c) The Nr and Nf scales were too cluttered and pilots complained about the lack of digital Nr data.
- (d) The T4 temperature strips were not large enough.
- (e) The digital readouts of T4 and Ng were useful. However, they were wasteful of display space when positioned on top of each strip which could move over a

significant part of the display. In addition, during engine starts, when the strip was moving quickly and the digits were also moving, the digits became difficult to read.

To overcome these deficiencies, the following changes and additions were made gradually to the TEES and PEES format over a period of several weeks of flight tests.

All of the fuel parameters and the torque display were grouped together on the LHS of the format.

To facilitate easier matching of fuel flows an analogue strip was placed above the digital readouts which showed the difference between the two rates of flow.

A digital readout of N_r , in addition to the strip display, was provided at the bottom of the analogue strip.

The digital readouts of T_4 and N_g were positioned below the corresponding strip scales.

A pair of horizontal lines, coloured magenta and cyan, and colloquially termed the tramlines, were drawn so as to intercept the T_4 , N_r , N_f and N_g strip scales. The strip non-linear scales were then adjusted so that the tramlines gave the upper and lower operating limits for each strip parameter.

To complete the format some simulated values of hydraulic and oil pressures and oil temperatures were also displayed together with their complementary tramlines.

The new TEES and PEES format is shown in Fig 5. A full description of the subsequent evaluation of this format is given in section 5.

4 THE HEALTH MONITOR

4.1 Failures and warnings

A health monitor was included in the flight management system. This monitored key data continuously and checked for any abnormal conditions. If a fault or alert condition was detected then the pilot was given an indication, in a variety of ways, depending on the severity of the problem.

An audio message was always given to the pilot. This ensured that he would be aware of the problem should he be concentrating on external visual cues and therefore not looking at internal cockpit displays. The audio warning in itself gave information on the nature of the problem. Many of the warnings were related to height limit exceedences. These were particularly useful during poor visibility recoveries. This set of warnings, which also embraced advisory height information could be inhibited by the pilot to avoid nuisance calls during deliberate low level manoeuvres. Table 1 shows the audio messages that were used.

Any parameter on a display which was outside a set of operating limits was colour coded magenta.

The CDU display could present a visual readout of the problem. For example, 'power turbine split'.

The MFD format could be automatically changed to show the relevant problem.

Table 2 presents a list of the conditions which were checked and the warning responses they produced.

4.2 Power performance index (PPI) and health monitoring

Since gas generator speed, power turbine inlet temperature, free turbine speed, rotor speed and torque were all monitored on line, together with outside air temperature, altitude and pressure, it was a logical step to incorporate the ability to calculate the Power Performance Index (PPI) for each engine. In the Wessex a single torquemeter served both engines. Hence any on-line PPI was only valid with one engine idling. With the PPI format selected the engine failure warnings were suppressed. With more modern aircraft which are fitted with a torquemeter for each engine, together with better engine models, on line PPI would be a simple and viable proposition. This would enable PPI trends to be monitored continuously, which would allow engine performance reductions due to icing or salt ingestion, to be flagged to the pilot on the CDU or MFD. A further advantage of on-line monitoring would be the possibility of lifeing engines on time spent at various compressor speeds and temperatures. This would allow engine condition to be judged on use rather than time alone. Thus an in-service operational engine which cycles infrequently, for example in AEW roles, may be given a longer service life than the same engine when used in the training role. This may ultimately provide a real potential cost saving and increase in engine reliability.

4.3 Aircraft performance

Having assessed the actual engine performance the next step was to calculate aircraft performance using the operating data manual (ODM) reference curves. It was thus possible to let the pilot know his hover and landing capability, tail rotor authority limits, and maximum allowed airspeed etc. These could be checked on the flight status page on the MFD (see Fig 6). However, to avoid the necessity of calling other MFD formats during critical conditions, such as an engine failure, the hover capability could be displayed on the TEES and PEES format. The pilot could ask for his current hover capability by pressing a cursor control on the cyclic flight control column. He did this when he was pulling as much power as the powerplant/transmission system would allow. A line of text above the torque display would then indicate the hover margin that was available. One of five readouts could be obtained corresponding to:

- hover out of ground effect plus 5% thrust margin or greater
- hover out of ground effect
- hover with a 10ft wheel clearance
- hover with bare wheel clearance
- no hover capability

These facilities allowed the pilot to operate on the edge of the flight envelope without having to refer frequently to his flight envelope graphs. This may be regarded as an initial step towards carefree manoeuvring.

4.4 Icing

The Wessex system monitored outside air temperature continuously. If it dropped below 10°C the pilot was alerted on the CDU and the pilot could refer to the icing limits on the MFD by selecting the relevant part of the status page. A future refinement could be to monitor the anti-icing switch and only alert the pilot if it was off under those conditions.

5 FLIGHT RESULTS

5.1 Engine starts

The TEES and PEES format was satisfactory for monitoring an engine start sequence, (see Fig 7). The possibility of a T4 exceedence could be spotted easily but if it was missed the health monitor provided a warning. The Ng readout enabled the high pressure fuel cock to be opened at the correct time and the ground idle conditions to be set. Pilots unused to the strange format, initially stated that they did not like it during the engine start phase. However, once the strips began to grow during the start sequence there was ample analogue information on the display to detect problems. This was demonstrated with some very hot and rapid starts experienced during the later phases of the trials.

Once both engines were running, the pilot, as part of the standard freewheel checks, would alternatively pull back each engine speed select lever (SSL). The automatic warning system would then produce a set of alerts which indicated to the pilot that the monitoring system was fully operational.

5.2 Flight monitoring

Once airborne, the MFD was normally used to display the navigation format which provided digital map, route, track, and waypoint data. Other formats, related to communications or flight status etc could be called up as required by the pilot. At irregular intervals, determined primarily by workload and the 'urge' to check the powerplant health, the pilot would call up the TEES and PEES format. This was strictly unnecessary because the health monitor constantly checked all parameters far more closely than the pilot could hope to. The tramlines and colour coding of the data enabled the pilot to extract two types of information very quickly.

(a) A parameter outside its normal operating limit. This would have been automatically indicated by the monitor. In addition, the parameter would be colour coded magenta.

(b) A parameter approaching a limit. This could be indicative of an impending problem. The relevant strip would be close to intersecting one of the tramlines.

Pilots found the format very easy to use and interpret. Once experience and hence confidence had been gained with the system, the philosophy of inhibiting engine displays, and having them presented automatically by the monitor, or called by the pilot, was accepted fully.

5.3 Warnings

Various failures and limit exceedences could be deliberately introduced in flight to exercise the monitor and determine the pilot reaction, including the subsequent actions to diagnose and remedy the problem.

(a) Simple problems such as exceeding 3000 ft/lb torque or exceeding the V_{max} airspeed occurred occasionally without any deliberate intention. The voice alert proved most effective and on no occasion did a warning go unheeded. The corresponding colour change of the torque strip (see Fig 13) or airspeed digits on the PFD reinforced the warning if the pilot looked at the display. It was notable that on many occasions, particularly for the torque warning, that the pilot immediately reacted on hearing the voice call 'torque' and did not look at the display.

(b) Intentional and, on a few occasions, unintentional warnings of fuel tank mismatch, fuel flow mismatch, or low fuel were produced. On these occasions the warnings and their associated display changes were unmistakable.

(c) Engine failures could be simulated by pulling back one of the engine speed select levers, see Fig 8. The audio warning, CDE readout and MFD format change together with the colour coding on the TEES and PEES format left little opportunity for incorrect diagnosis. In particular, the resultant asymmetric engine layout produced a display which was easy to interpret. Although not all failure types could be simulated, such as an engine runaway, pilots felt that they would be very unlikely to misinterpret the nature of the problem with such a presentation.

(d) Nuisance warnings were very rare, which was a good feature of the system. In addition, the priority attached to warnings and the inhibition of sub-sets of warnings, in the event of a higher priority problem, were well liked. The effect was to produce a system to which pilots quickly adapted and which did not create high workload or stress when activated.

(e) It was noticeable at times that when a sequence of warnings was triggered there could be a finite delay as the system selected and displayed the warning. Fig 9 illustrates one example. Following a fuel flow split, there would be a fuel flow split, compressor speed rundown, fuel flow split, high or low turbine temperature, possibly low rotor speed and possibly high compressor inlet temperature on the other engine. In this example, priority warnings would be issued for low rotor speed because, without it, the engine would be unable to start or run in a normal operational system, a great deal of effort would be required to establish the priorities of warnings during different failure modes and the pilot would have to process a great deal of information quickly.

(f) When dealing with a warning, the pilot has the capability of determining resultant hover capability. This is done by pulling back the lever that the controls the pilot would pull power to the maximum available, depressing the throttle cursor presented the hover capability.

5.4 Checks

The ability to call up checks in association with some aspect of the TEES and PEES format was useful. For example take off checks and the engine data were a good combination which pilots would use before take off (see Fig 10). The combined format reduced the amount of pilot selection required to check the aircraft systems.

Similarly, when dealing with problems such as an engine restart in flight, or hydraulic failures, the relevant checks and data could be presented together (see Figs 11 and 12).

5.5 Layout of the TEES and PEES format

The format was designed such that parameters were grouped by engine rather than the type of data. This was to make identification of failure or malfunction easier. If one engine or one section of the transmission failed one could expect to find all the information pertaining to that equipment in one area of the display. Thus following a failure one area of the display would be of different size (bigger or smaller) and/or a different colour. If the display parameters were arranged by type of parameter the pilot would be required to interrogate each individual element of the display and identify each correctly in order to diagnose the problem. This would not necessarily be difficult for simple or familiar malfunctions but rarer problems such as a freewheel failure, require careful diagnosis.

Another element of the format, which eased the identification of problems, was the introduction of the 'tramlines'. The display was arranged so that if all of the analogue strips were within their operating tolerances they would appear within the tramlines. Those outside their operating limits would be outside the lines and would change colour. To achieve this design, non-linear scalings were adopted. This meant that not only was fault diagnosis easier but power checking and engine condition checks, such as when carrying out PPIs, were also easier. For example, when taking off, the pilot could complete his take-off checks by simply checking that all of the strip data were between the tramlines.

For twin engine operation the display was configured to indicate the twin-engine limits. With one engine inoperative the display was reconfigured to display single engine limitations. This saved the pilot considerable time and effort in re-assessing the new situation. The new operating limits could still be determined by the pilot by accessing a limits page in the status page of the CDU. This could be used to display a colour format on the MFD describing the single engine operating limits for the rotor, transmission and engine systems.

5.6 Primary flight display

A vital parameter in the helicopter which needs to be monitored carefully is the rotor speed. During autorotation exercises in particular, it was discovered that pilots felt that this data should be treated as primary flight information and moreover that it should occupy a prime position on the PFD. Figs 2 and 13 show the rotor rev/min displayed in the top centre position. When within its normal operating limits this

appeared as a single white vertical line which was centred on the zero line. If rotor speed was outside its normal governed range (230 to 250 rev/min) the analogue strip extended from the white line. The strip extended left and was coloured magenta if the speed was less than 230 rev/min. The strip extended right and was coloured magenta if the speed was above 250 rev/min. The analogue strip was replaced by digital readouts when the rotor speed was less than 230 or greater than 250 rev/min. These limits corresponded to the maximum transient excursions allowable.

Audio warnings were used to reinforce any visual alerts of rotor speed variations. A compromise between too many nuisance warnings and providing the pilot with the earliest indication possible of excessive rotor speed variations, resulted in the alert trigger points being set to 225 and 245 rev/min.

Torque was displayed as a vertical strip on the LHS of the display. A digital readout to the nearest 100 ft lb was displayed below the strip. A horizontal magenta line was drawn across the display to indicate the maximum continuous torque limit. If both engines were running this was set to 3000 ft lb and if one engine was inoperative then it was automatically set to 2750 ft lb. If the torque exceeded this limit then the whole strip changed colour from white to magenta and a voice alert 'torque' was issued. This voice alert repeated every 7 s until the demanded torque fell below the line once more.

This format was effective, it was located on the LHS of the display together with all the other collective related data such as height, rate of climb and descent, and height director. It presented all the information the pilot needed on a primary flight display, ie what torque (or power) he was using and what torque (or power) was available.

It is considered that the pilot needs no engine related information on his PFD beyond rotor rev/min and torque (or power) available. Indeed additional data may only serve to clutter this format and slow down the pilots assimilation of information.

6 CONCLUSIONS

The Wessex trials have shown that the display of engine related data could be suppressed and only shown when demanded by the pilot or the health monitor. Such a philosophy was acceptable to all the pilots who flew the aircraft. In addition, such a system removed the need for a permanent and dedicated display of powerplant data. Thus the total number of display surfaces required can be reduced. This could provide room for other equipment, increase the outside visibility, or for the same number of displays increase the reliability through improved redundancy.

A powerplant display format which groups data elements by engine rather than function enables fault conditions to be diagnosed more readily and quickly.

The ability to monitor engine power performance in flight was demonstrated. This should enhance safety and reduce operating costs and could pave the way for engine life to be measured on a more meaningful basis, such as counts, rather than straight running hours.

The use of synthetic voice alerts as part of an integrated management and failure warning system has been shown to be very effective. It ensures that pilots react promptly to failures, particularly when concentrating on external visual cues and therefore unaware of display mode changes.

The use of gross but simple symbol colour changes, to highlight problem areas on display formats, has been shown to be very effective. When combined with a format which groups data by system the time to diagnose failures is reduced, as is the likelihood of the wrong diagnosis.

An integrated cockpit monitoring and display system of this type would allow the pilot to concentrate upon tasks more relevant to the current phase of flight. This in turn will increase safety and mission effectiveness.

Appendix A

THE WESSEX FACILITY

A.1 The cockpit

Fig 1 is a photograph of the Wessex cockpit. The left hand side (LHS) of the instrument panel was the subject pilot's position and the controls and displays available to him were as follows:

- Two colour displays (one with a touch overlay)
- A control and display unit (CDU) with touch sensitive overlay
- 16 key keyboard
- Automatic speech recognition (ASR)
- Synthetic speech output (SSO)
- Cursor controls and ASR activate switch on cyclic
- Map joystick on collective

The right hand (RHS) instrument panel was used by the observer or safety pilot. Either of the two current display formats could be selected and shown on the RHS tube. A full set of standard electromechanical instruments were retained for use by the safety pilot, for critical sorties such as evaluations of instrument flight in IMC. All the aircrew could hear the SSO.

A.2 Colour displays and formats

The colour displays were standard commercial monitors which were fed with video (domestic standard PAL) signals. A video switching and distribution system enabled any colour CRT to display either of the two formats which were available at any one time. One of these formats which was always displayed, was the primary flight display (PFD). This format displayed sufficient information to enable the pilot to control, navigate, approach and land the helicopter, in visual and instrument flight. Using, dedicated keys or the control and display unit (CDU) the subject pilot could choose to display one of a number of formats on the second multifunction display (MFD) CRT. In addition, with a map format selected the GEC avionics tactile overlay could be used to designate a waypoint.

A.3 Control and display unit

The control and display unit consisted of a monochrome CRT with a touch sensitive overlay, dedicated keys to the left and right of the CRT, and a numeric keyboard.

Several points should be noted about this configuration.

(a) The CDU screen was in a 'chin-up' position which was considered to be a very desirable feature. Previous trials had shown that the CDU could absorb much of the pilot's time and concentration. For helicopter operations it was essential that as little time as possible was spent looking inside the cockpit while managing the avionic systems. Many existing cockpits deny the pilot this capability by placing the CDU screen and keys in the lower inter-seat console area.

(b) The CDU screen and surrounding area was extended out from the instrument panel towards the pilot without conflicting with the flight controls or access. This not only placed the CDU in a much more accessible position for the pilot to control but gave the colour monitors underneath some protection from direct sunlight.

(c) The cyclic control did not obstruct any of the colour displays from the pilot.

(d) The pilot's field of view of the external world was substantially the same as with the conventional instrument panel.

(e) Although perhaps lower than ideal, the PFD and MFD were no lower than many of the existing or previous conventional instruments and were still highly visible.

A.4 Automatic speech recognition

In recent years many commercial automatic speech recognition (ASR) systems have become available which showed promise for use in airborne applications. The automatic speech recognition system selected for the Wessex trials was an SR-128 manufactured by Marconi Secure Radio Systems. This was a stand-alone device suitable for mounting in 19 inch racks. It was powered from the 115 V 400 Hz instrumentation inverter to allow it to be used in the helicopter from start-up to shutdown. Speech input was via a 600 ohm balanced line, recognition and control data were passed on RS232 serial lines.

The main features of the SR-128 were as follows:

- Speaker trained
- Vocabulary size of 240 words maximum
- Syntax programming
- Ambient noise compensation
- RS232 interfaces
- Self contained mini-cassette handler for programme and voice template loading.

Speech input from the pilots microphone was buffered in a remote pre-amplifier before entering a 600 ohm balanced input at the ASR. A rocker switch on the pilots cyclic control column (previously used as the intercom override) was used to switch the pilots microphone output from the intercom to the pre-amplifier and ASR. This prevented the DVI system from attempting to recognise words not intended for it. The speech vocabulary is shown in Table 1.

A.5 Synthetic speech

A synthetic speech facility which could be used to give audio messages or warnings to the pilot was designed and installed in the processing and interface unit. This was based on a Texas Instruments 5220 linear predictive coding speech processor and could store up to 500 words of vocabulary. Simple commands from the main processor could then select a word or group of words, its volume and its priority for output if more than one word or phrase was called. Any vocabulary could be programmed using any voice by using a complementary portable speech laboratory specifically produced by Texas Instruments for that task. This facility enabled a user to program any words or phrases

into programmable read only memory (PROM) which was then inserted into the speech interface card. The voice output was fed into the aircraft intercom system via an on-board amplifier. The synthetic speech could be totally isolated from the intercom by a selection on the intercom/radio station box. The speech output vocabulary is shown in Table 3.

A.6 Avionics and interfacing

The flight management processors were interfaced to each other to the waveform generators and the following systems and sensors:

- Doppler groundspeed sensor
- Airspeed
- Heading, pitch, roll attitudes
- Barometric pressure
- Outside air temperature
- Radio altimeter
- Normal and lateral accelerometers
- Collective and cyclic control positions
- Guidance systems ILS, MLS and MADGE
- Engine and transmission:
 - Power turbine speeds
 - Compressor speeds
 - Power turbine inlet temperatures (PTIT)
 - Fuel flows
 - Fuel contents
 - Rotor rev/min
 - Torque
- UHF/VHF PTR 1751 Radio (Digitally controllable)
- Digital map
- Automatic speech recogniser (ASR)
- Synthetic speech output (SSO)
- Non volatile memory
- Radio clock

In addition, audio, video and digital recording systems were used to record the display formats, pilot intercom, radio, and the sensor information.

Appendix B

TRIALS PROGRAMME AND PROCEDURES

Once the cockpit had been commissioned and the major hardware and software bugs had been removed, a period of intense flying was conducted to refine and optimise the use of the system. The aim was to ease the pilot's workload and hence improve mission effectiveness.

Although individual equipment performance was an important factor and, where possible, was measured, emphasis was placed on discovering how and where the new technology could be applied to derive the maximum benefit.

B.1 Pilots

Three service pilots were used to develop and evaluate the total display and flight management system. This enabled pilot opinion, expertise, and a knowledge of operational problems from a wide background to be used in the trials. As each pilot had to attain and maintain a good level of understanding and proficiency with the system, it was thought that further pilots would have diluted the amount of useful flying that could be achieved. It should be noted however, that over 80 pilots from the Services, Civil operations and UK Industry have flown in the Wessex and received demonstrations of the equipment and ideas in operation. Their comments have been taken into account during system development and evaluation.

B.2 Trial sorties

From the initial conception of the programme it was appreciated that the flight management and display system could have an impact on both military and civil operations. Hence tasks were given to the pilots to cover both types of operations, such as general manoeuvres in visual flight. However, others such as nap of the earth (NOE) flight (low level flight using the maximum cover afforded by natural and man-made obstructions), were obviously aimed at the Services. The list below gives an indication of the tasks used and the main reasons for adopting them:

(a) Low level navigation by day in VMC

- Navigation accuracy during NOE flight
- Hands on control of cockpit management system
- Benefits of speech recognition
- Benefits of synthetic speech
- Cable/threat warnings display logic
- Use of the chin-up CDU during a primarily head-out operation
- Overall system effectiveness

(b) Low level navigation at night

- All items listed in (a)
- Night vision goggle compatibility with digital maps
- Primary flight display format development
- Overall system assessment during a very demanding task

- (c) Medium level navigation in visual and instrument flight
 - Navigational accuracy compared to task (a)
 - Performance prediction, fuel management, endurance monitoring
 - Radio management in multi radio/frequency areas (eg London Control Zone).
 - Primary flight display development
 - Multi function display format development
 - CDU menu structure
- (d) Low speed manoeuvres
 - Hover display format
 - Low speed envelope prediction
 - Digital map targeting
 - Speech recognition benefits
 - Synthetic speech benefits
- (e) Terminal/approach guidance
 - Primary flight display development
 - Synthetic speech during instrument flight
 - Use of digital maps for self-positioning tasks
 - MLS and ILS formats
 - Speech recognition benefits
- (f) General flying/crew training
 - Primary flight display format
 - Development of logic/artificial intelligence to signal malfunctions to the pilot

Table 1
AUDIO WARNINGS

Event	Speech output
Port engine temperature > limit	Check port T4
Stbd engine temperature > limit	Check stbd T4
Port compressor rev/min > limit	Check port compressor
Stbd compressor rev/min > limit	Check stbd compressor
Power turbine mismatch (needle split)	Warning engines
Fuel flow mismatch > limit	Warning fuel mismatch
Fuel tank contents mismatch > limit	Check fuel
Fuel in either tank < limit	Warning check fuel
Rotor speed out of limits	Warning check Nr
Torque > limit	Torque
Cable detected	Warning
Radar detected	Warning
Airspeed > maximum allowed (V_{max})	Reduce speed

Height Related Warnings and Advisory Information

If height > 248 and height < 252	Two fifty
If height > 198 and height < 202	Two hundred
If height > 148 and height < 152	One fifty
If height > 98 and height < 102	One hundred
If height > 88 and height < 92	Ninety
If height > 78 and height < 82	Eighty
If height > 68 and height < 72	Seventy
If height > 58 and height < 62	Sixty
If height > 48 and height < 52	Fifty
If height > 38 and height < 42	Forty
If height > 28 and height < 32	Thirty
If height < decision height	Decision height
If height > desired height on directors	High
If height < desired height on directors	Low
If height < set height for radar	Pull up pull up

Table 2

HEALTH MONITOR CHECKS

Port PTIT > 685°
Stbd PTIT > 685°
Port PTIT > 710°
Stbd PTIT > 710°
Port compressor rev/min > 26300
Stbd compressor rev/min > 26300
Power turbine split
Port fuel flow freeze
Stbd fuel flow freeze
Fuel flow mismatch
Compressor rev/min > 26750
PTIT > 710°
Port fuel < 100 lb
Stbd fuel < 100 lb
Fuel weight imbalance > 400 lb
Rotor rev/min out of limits
Torque limit exceeded
Flight envelope exceeded
Limited yaw control
Maximum airspeed (V_{max}) exceeded
Outside temperature < 10°
Height < set low height
Height outside director height limits
Radar alert (simulated)
Cable alert (simulated)

REFERENCES

<u>No.</u>	<u>Author</u>	<u>Title, etc</u>
1	R. Little	The development of an electronic cockpit display and flight management system for helicopters. RAE Technical Memorandum FS(B) 586 (1985)
2	R. Little Lt Cdr R. Cowan	The flight evaluation of a speech recognition and a speech output system in an advanced cockpit display and flight management system for helicopters. RAE Technical Memorandum FS(B) to be published

Fig 1

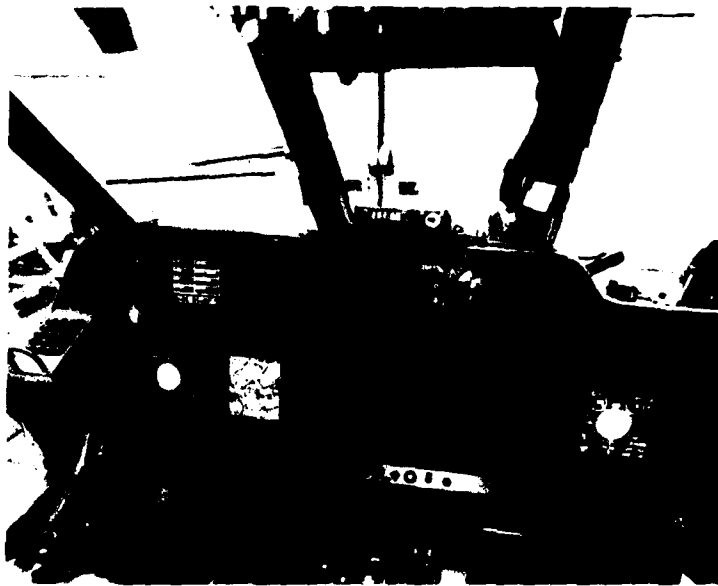


Fig 1 The Wessex Cockpit

Figs 2-5



Fig 2 Primary Flight Display
(rotor rev/min middle/top)

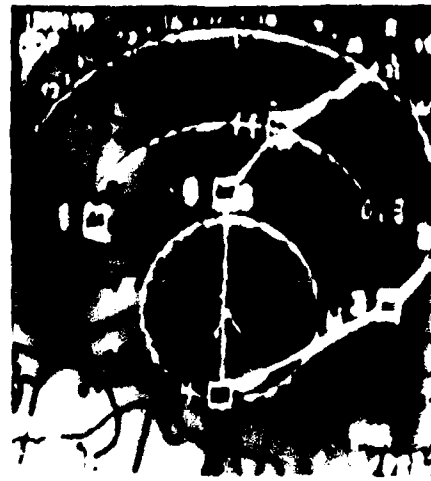


Fig 3 Navigation format

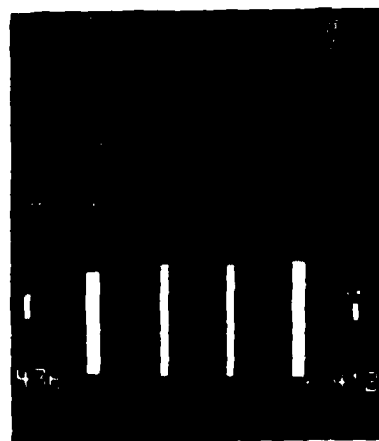


Fig 4 An initial TEES and PEGS
format



Fig 5 The present TEES and PEGS
format

Figs 6-9

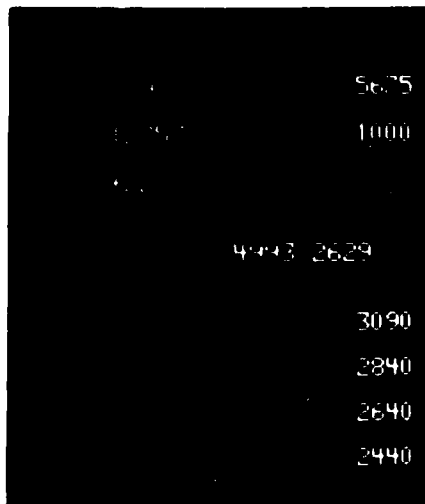


Fig 6 Flight status page

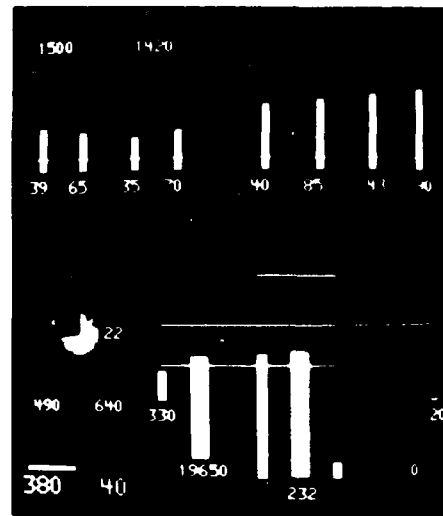


Fig 7 Port engine running

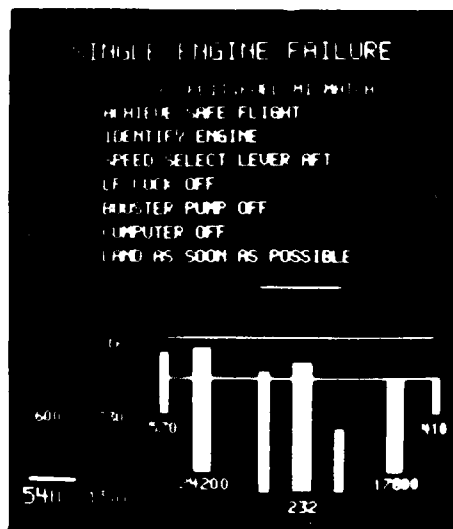


Fig 8 Simulated starboard engine failure in flight

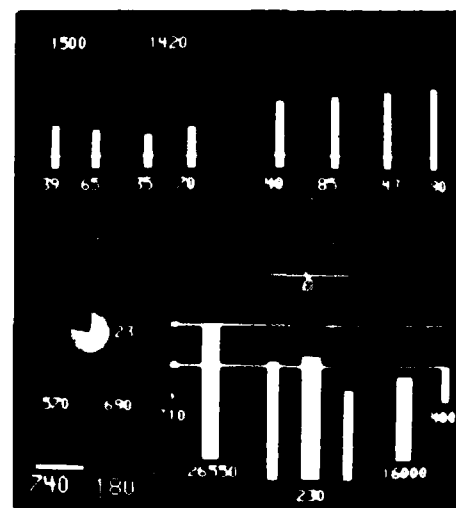


Fig 9 Starboard engine failed port engine at limits

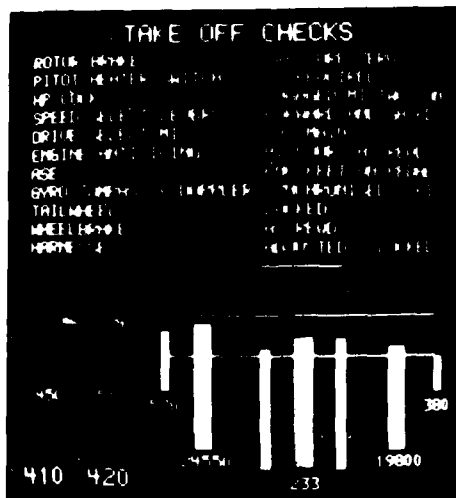


Fig 10 Take-off checks

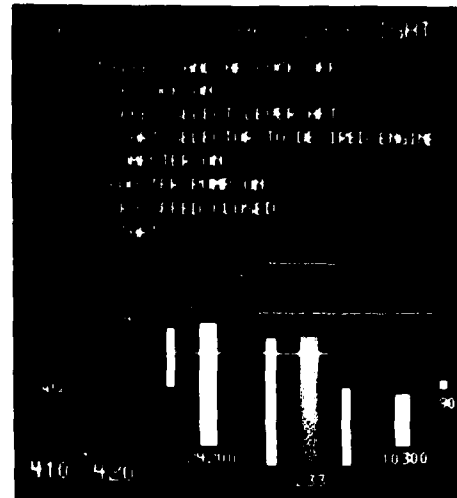


Fig 11 Engine restart checks

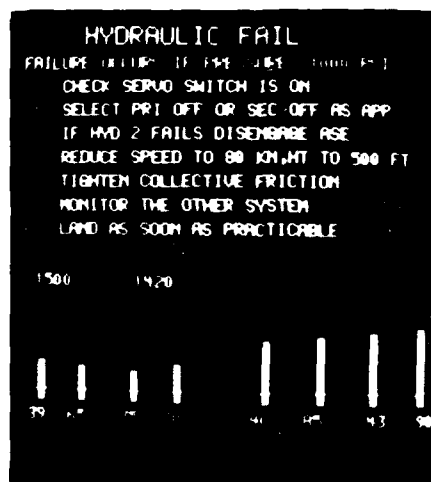


Fig 12 Hydraulic failure checks

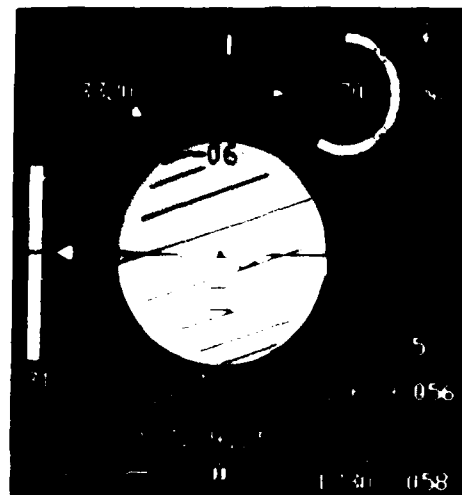


Fig 13 Primary flight display

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNCLASSIFIED

Instructions for completion appear overleaf.

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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST) Engine Display. Voice Alerts. Electronics Displays. Failure Warnings. Helicopter.				
17. Abstract A Wessex helicopter at RAE Bedford has been used to develop and evaluate an integrated avionics system which incorporated electronic displays and a flight management system for both military and civil applications. A key feature of this system was the display of engine and transmission data. This was complemented by a system monitor which provided visual and audio warnings of limit exceedences, parameter mismatches, and failures. The flight trials showed that the display of engine and transmission data could be advantageously suppressed and only shown when the pilot requested it or a monitor detected a problem. When used in combination with synthetic voice the monitoring system allowed the pilot to concentrate upon tasks more relevant to the current phase of flight. Safety and mission effectiveness were therefore enhanced.				

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